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# Multidetector Row CT of the Small Bowel

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Several factors continue to make multidetector row CT (MDCT) of the small bowel difficult: inherent anatomic limitations, specific challenges because of the pathology sought, and technical constraints. The small bowel is an organ several meters long with a tortuous and variable course prone to change with breathing and peristalsis, and a thin wall difficult to display with imaging. The small bowel method of fixation to the rest of the body (the mesentery) and its blood supply are both complex. In addition, because small bowel diseases have a low incidence, their appearance is less well known and there is an increased risk of missing them. Even for most of the common diseases in the small bowel, early changes are subtle making their diagnoses difficult.

Imaging the small bowel is challenging technically. Because the organ is long and serpentine, a large field of view and a large volume are needed to display it in its entirety. Another problem for imaging is motion, both the intrinsic motion of peristalsis and the positional changes caused by breathing. These two motion patterns can be additive and lead to a complex movement of individual bowel loops, making their tracing very difficult.

The ideal diagnostic imaging tool for the small bowel displays its bowel wall, with detailed information of its mucosal layer; depicts the entire small bowel tube; and provides information about adjacent structures, such as mesenteric and omental fat. To diagnose changes in the mucosa, sufficient and reliable bowel distention has to be obtained. These prerequisites can only be partly fulfilled by most standard methods. Endoscopy and capsule endoscopy can provide a detailed view of the mucosal layer but deeper layers of the bowel wall and the adjacent tissues are out of its diagnostic reach. Conventional small bowel fluoroscopy with enteroclysis provides reliable diagnosis of mucosal changes and can depict indirect findings of deep bowel wall and surrounding tissues, but still has clear limitations in these areas [1].

The development of MDCT allows high-resolution imaging of the whole abdomen in one breathhold obviating motion artifacts. With this acquisition method, a whole abdominal volume can be obtained instead of only single slices as with earlier CT units. Using this volume data set for reconstructions allows concise display of the small bowel [2]. New developments in patient preparation provide stable distention of the small bowel.

For years, the standard of reference for small bowel imaging was fluoroscopic small bowel follow-through (SBFT) and enteroclysis. With the fast and widely available MDCT at hand, however, attention has shifted toward this technique to diagnose small bowel pathology [3]. This article discusses the current status of MDCT for small bowel imaging, gives an overview of the technique and the different oral preparation methods possible, and discusses the normal anatomy and the most common small bowel diseases as detected and characterized with MDCT.

## Technique

There are several challenges in imaging the small bowel. Ideally, CT of the small bowel should include optimal image acquisition, oral contrast and intra-

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venous (IV) contrast administration, and multiplanar reconstruction in the postprocessing phase.

### *Technical CT considerations*

With MDCT, with one breathhold the whole abdomen can be covered. Suspended respiration is an essential aspect for successful imaging of the small bowel. Even with fast MDCT it is not possible to obtain artifact-free images if there is free breathing. The length of the apnea phase is a limiting factor for adequate imaging. The acquisition time must be limited to a maximum of 25 seconds. The newest MDCT units have no time constraints and with 64-row models to scan multiple contrast phases within a breathhold representing a challenge to optimize IV contrast administration. For a good-quality image, a voxel size below 2 mm is recommended.

The current CT protocol the authors use for small bowel evaluation is as follows: oral contrast administration with 1350 mL of VoLumen (EZEM, Lake Success, New York) taken continuously over a period of 45 minutes before imaging. The patient is imaged in supine position at 40 and 70 seconds after IV administration of 100 mL iopromide (Ultravist 300; Berlex, Montville, New Jersey). For 16-row images the authors use a 0.75-mm collimation and for 64-row a 0.6-mm collimation. All image data are reconstructed in axial, coronal, and saggital planes (Table 1).

### *Reconstruction methods*

With standard MDCT scans of the abdomen using slice thickness of less than 2 mm and an approximate coverage in the z-axis of 90 cm, several hundred slices are acquired. The resulting mass of data requires special technical capacities to handle these several hundred images. This is why all abdominal MDCT scans use reconstruction methods image interpretation. Reconstruction is not only done in coronal and saggital planes but also in the axial plane, resetting the slice thickness (usually 3–5 mm) to a thicker size than the one scanned. The technique of reconstruction should be implemented on all workstations for immediate availability of the needed views. With modern MDCT technique, the in-plane and through-plane resolution is the same, leading to isotropic voxel resolution in the volume, which makes reconstruction in all planes possible without loss of information.

Coronal reconstruction seems to be especially important for small bowel imaging because of the anatomic arrangement of the loops [4]. The possibility of having all three planes available also helps to follow the bowel loops throughout the abdomen. Complex reconstruction techniques, such as surface rendering or virtual fly-through, do not seem to offer any improvement over the diagnostic accuracy of two-dimensional viewing of MDCT images. Thick-slab rendering seems a promising technique for the diagnostic display of the small bowel (Fig. 1). With this technique, a thicker slab of the initially acquired volume is extracted. This display method has the advantage of high-resolution imaging (which is lost in other methods of displaying radiologic information of the abdomen) and the physical possibilities of volumetric information. This technique is very helpful in giving information about complex structures in a limited space, such as the mesenteric artery, the vasa recta to the bowel, and duodenum and proximal jejunum folds.

### *Intravenous contrast*

The peroral contrast must be combined with IV contrast. Specifically, the combination of neutral oral contrast and IV contrast gives a very good display of the bowel wall [5]. Inflammatory bowel disease and neoplasm are optimally displayed with the use of IV contrast [6]. Nonionic iodinated contrast is most

Table 1
Parameter list for multidetector row CT of the small bowel

| CT type | Oral | IV | Delay (s) | kV/Ma | Collimation | Recon | MPR |
|---|---|---|---|---|---|---|---|
| 16-row | 300 mL VoLumen given at 1 h, 45 min, and 30 min before scan. Add another 300 mL on the table prior examination. | 100 mL iopromide 300 at 3–5 mL/s | 40 and 70 | 120/180 | 0.75 | 5/5 | 3 cor;<br>1.5 sag |
| 64-row | As above. | 100 mL iopromide 300 at 3–5 mL/s | 40 and 70 | 120/200 | 0.6 | 5/5 | 3 cor;<br>1.5 sag |

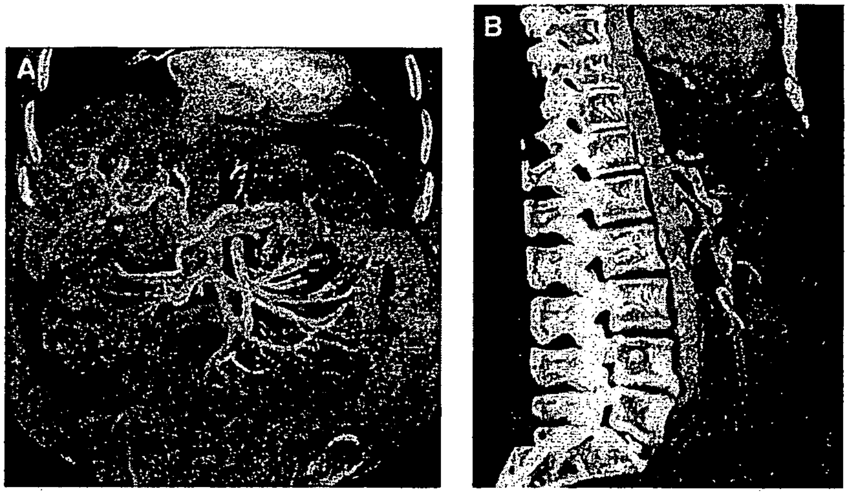

Fig. 1. The combination of submillimeter slices and volume acquisition provides the option for multiplanar reconstructions. Working directly on workstations one can easily reconstruct the mesenteric vessels in both coronal (*A*) and saggital (*B*) planes. The use of thin slab maximum intensity projections can be helpful in getting an overview of complex bowel structures. (Courtesy of Ralph Berther, MD, Winterthur, Switzerland.)

widely used today. The ideal volume and injection rate are 125 mL and 3 to 4 mL/s, respectively. For detailed display of the mesenteric vasculature, a higher volume (150 mL) and a higher flow rate (4–5 mL/s) are chosen. The peak contrast enhancement of the bowel wall has a different timing than the liver [5]. A 60-second scan delay is ideal to acquire the small bowel wall in its best enhancement phase, whereas 70 to 90 seconds is best for liver imaging. If there are additional questions about the liver, add the upper abdomen to the liver phase of the scan protocol.

### *Oral contrast and distention*

For an optimal display of the bowel, two things are essential in imaging: intraluminal contrast and distention. Intraluminal contrast is needed to delineate bowel loops in the abdominal cavity, to tell different loops apart, and to depict the bowel wall. There are three ways to contrast the bowel: (1) positively, giving the contents an increased density compared with their surroundings; (2) neutral, using an intermediate density contrast; and (3) negatively, with a contrast of low density. Distention in small bowel imaging is essential to unfold the bowel tube and separate out the bowel wall. It is nearly impossible to find subtle pathology in collapsed bowel loops [7–9]. With standard oral contrast administration for abdominal CT, the distention of the small bowel is not sufficiently achieved and different methods of oral contrast have been developed.

In imaging the small bowel these intraluminal contrast and distention are inseparable. Many authors speak of oral contrast when they actually mean the combination of contrast and distention.

Several techniques are available to combine optimal contrast and distension (Fig. 2). Two different application methods carry the contrast to its required site: peroral (noninvasive) or CT enterography and administration of contrast by a nasogastric tube or CT enteroclysis. The next sections explain the different contrast and application techniques.

### *CT enterography*

#### *Positive intraluminal contrast*

Positive oral contrast produces a high density to the bowel content and clearly delineates the bowel. Barium sulfate or iodinated solutions are used. Barium should only be used in very low doses to prevent artifacts, commercially available in concentrations of 2.1% (Readi-CAT; EZEM, Lake Success, New York) [10]. The iodinated contrast agent meglumine diatrizoate (Gastrographin) is the most widely used agent for CT. Both barium and iodated bowel contrast have wide acceptance and a low adverse-event rate [11]. The use of positive oral contrast leads to a diminished display of the bowel wall because of the high density of the lumen and the consequently decreased contrast between bowel lumen and wall. Additionally, multiplanar reconstructions (eg, of vascular structures) are hampered by the positive contrast [3]. Another problem with these

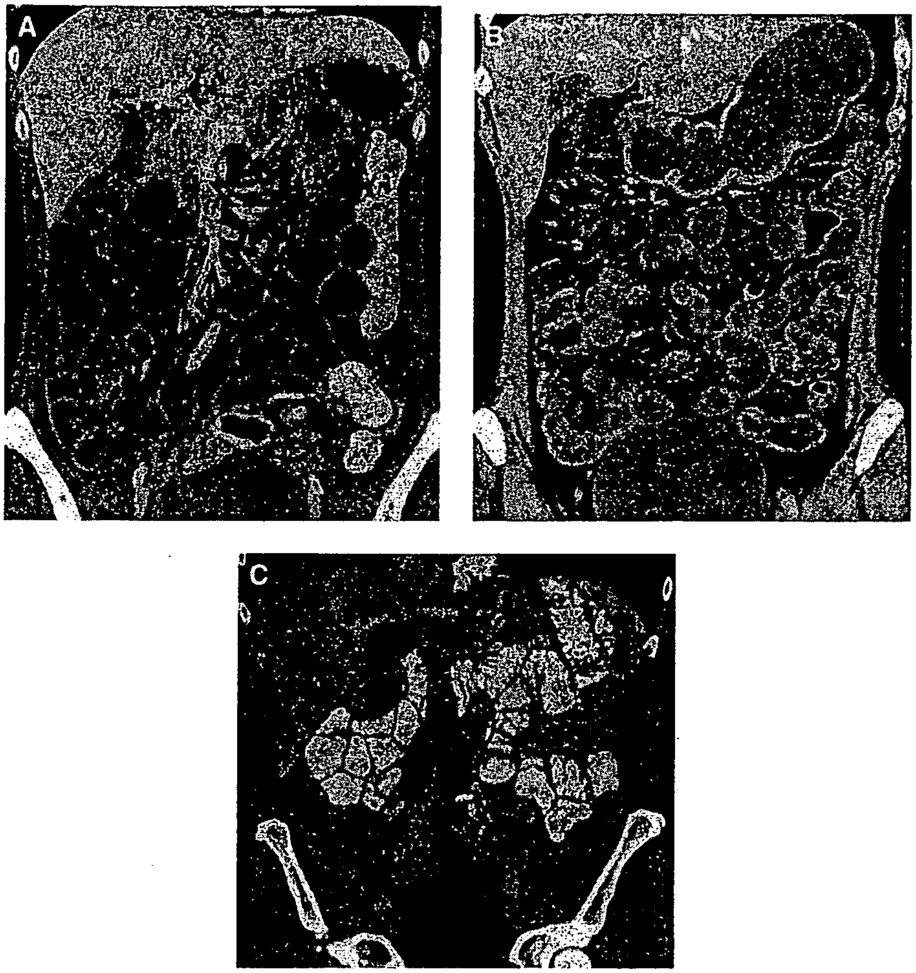

Fig. 2. Coronal reconstructions of different contrast agents for CT enterography. Mannitol (*A*; courtesy of Ralph Berther, MD, Winterthur, Switzerland) and VoLumen (*B*) are neutral contrast agents with water-like densities. Meglumine diatrizoate (*C*) is a positive contrast agent giving the content of the small bowel a higher density. Mannitol and VoLumen provide good distention of small bowel loops, whereas meglumine diatrizoate has a tendency to be absorbed and of showing collapsed bowel segments, especially in the proximal segments.

agents is their relatively low distending capability. The risk with high intraluminal signal is to obscure the bowel wall and to miss an enhancing tumor [2].

### *Neutral intraluminal contrast*

Contrast agents that have an intermediate density (10–30 HU) in MDCT are called neutral. These oral contrast agents are used with increasing frequency [12]. In combination with IV contrast, they provide very good display of the bowel wall. The most widely used neutral oral contrast agent is water. It is inexpensive and universally available, but water alone is not an ideal contrast agent, because it is absorbed early in the gastrointestinal system and is not available in the mid and distal section of the small bowel [5]. To overcome early absorption, additives that increase the osmolarity of the water are used without changing the contrast characteristics. Mannitol [13,14] or other long-chain sugars can be used. The adverse effects of these additives are nausea and diarrhea.

A newly introduced neutral oral contrast agent is VoLumen. It is based in oral barium sulfate solutions containing all the additives but with only 0.1% of barium sulfate. With such a low concentration of barium it has no possible contrast effect in MDCT and even though containing barium, it is considered a neutral contrast agent. Compared with water or meglumine diatrizoate, VoLumen creates far better distention and the display of the bowel wall is very clear compared with these intraluminal contrast agents [15].

*Negative intraluminal contrast*

Negative contrast agents display a density below 0 HU in MDCT and are normally fat based. Although they provide a good distention and can result in a good visualization of the small bowel wall they are not so widely used [16–18]. There are some studies showing that carbon dioxide could work as a negative contrast but it is very difficult to apply and patient tolerance is low [19].

*CT enteroclysis*

A fundamentally different approach to small bowel imaging is CT enteroclysis [20]. Because the peroral administration of contrast is not controllable and needs good patient compliance, some centers use enteroclysis in combination with MDCT for small bowel imaging.

In enteroclysis, a nasojejunal tube is placed under fluoroscopy. With the tube in place, the patient is transported to the CT suite, and there the contrast is applied under direct CT fluoroscopic control. With this technique the distention is closely monitored dynamically. The advantage of this method is the close control of the distention and the dynamic filling of the bowel loops under CT fluoroscopy (Fig. 3). The placement of the nasoduodenal tube, however, is unpleasant for patients [21]. It is also invasive, with all the accompanying risks, and needs additional ionizing radiation for tube placement, which is an issue for female patients of childbearing age.

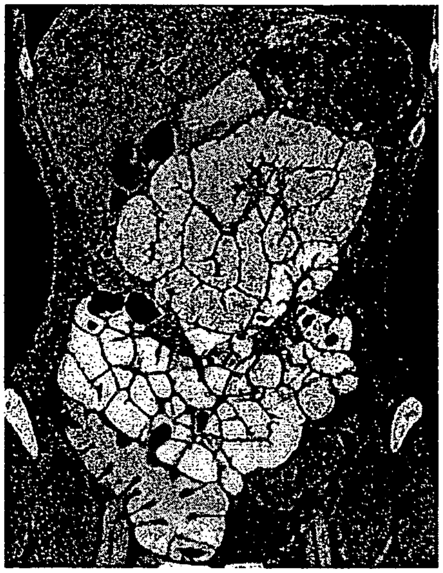

Fig. 3. Enteroclysis. A nasoduodenal tube is placed under fluoroscopy. With the tube in place the bowel is filled with a positive contrast agent, and then the patient is transported to the CT suite and images are acquired. Administration of contrast with a nasoduodenal tube allows the radiologist to have a well-controlled distention of the small bowel; usually a better distention than with orally administered contrast media. The placement of the tube is cumbersome and perceived as unpleasant by patients. (Courtesy of Simon Wildermuth, MD, Zurich, Switzerland.)

With intensive research on peroral contrast agents, there is an ongoing discussion about the benefit of enteroclysis, but there is evidence that CT enteroclysis is the choice imaging method for diagnosing low-grade small bowel obstruction (SBO) [22,23]. It increases its detection rate and can reveal the cause of obstruction. CT enteroclysis can also be used as a next-step diagnosis in Crohn's disease (CD) after standard technique MDCT, instead of SBFT [6]. Larger studies are needed to confirm the higher diagnostic value of CT enteroclysis versus CT enterography.

## Normal anatomy

The small bowel is an intraperitoneal structure, except for the duodenum, which is retroperitoneal. The total length of the small bowel measures 4 to 5 m in autopsy samples; in vivo its length is approximately 2.5 to 3 m. Its course is complex and has been referred to as "a pond of withering snakes" [24], extending roughly from the left to the right upper quadrant, down to the left lower, and then to the right lower quadrant. It is not possible on MDCT images to distinguish exactly between jejunum and ileum, but one can guess by their location in the abdominal cavity. The normal bowel wall thickness by MDCT seems 4 mm or less and can enhance brightly [5]. The thickness may vary depending on distention, but thickness of >5 mm is deemed always pathologic, independent of its distention [25]. The small bowel folds should be visible in the duodenum and the jejunum but are not visible in the ileum. The mesentery is the fixation point of the bowel loops and also provides the vasculature and the lymphatics of the small bowel. Between two thin layers of peritoneum, the mesentery contains mostly fat. The entire small bowel is supplied by the superior mesenteric artery and drains to the superior mesenteric vein and then to the portal vein.

## Disease

Small bowel diseases are rare. This article discusses the diseases that most commonly affect the small bowel, such as inflammatory bowel disease, obstruction, ischemia, and neoplasm. A recently published single-center study represents the distribution of disease in 107 patients, which were referred for small bowel MDCT in an 18-month period. The distribution of the diseases in this study was as follows: small bowel masses (18%), CD (10%), obstruction (10%), and normal findings in the rest. The overall sensitivity was 100% for detecting small bowel disease with MDCT, specificity was 95%, and accuracy was 97% [6].

### *Crohn's disease*

CD is an idiopathic inflammatory condition that may include all segments of the gastrointestinal tract. Approximately half a million patients in the United States suffer from this disease [26]. Large reviews have found that two thirds of these patients have some involvement of the small bowel, with 10% to 30% of them in the small bowel alone [27,28]. Symptomatic patients may have active inflammatory disease, chronic changes, or conditions not related to CD. The aim of imaging should be to establish the following: (1) presence, severity, and extent of the disease; (2) its activity; and (3) extraintestinal complications [29].

The classic imaging method to study CD is fluoroscopic SBFT, but the use of MDCT as the primary imaging technique for CD is gaining acceptance, especially because the use of neutral oral contrast media allows depiction of subtle bowel wall changes not possible with positive intraluminal contrast. Another emerging technique to diagnose CD is wireless capsule endoscopy, which is highly sensitive for early disease manifestations, such as small mucosal changes [30]. It is only applicable in patients without strictures, however, because it carries the risk of obstruction [31,32]. For safety reasons, every CD patient should have imaging before wireless capsule endoscopy, ideally by MDCT.

Large studies have evaluated the sensitivity and specificity of MDCT for detection of CD using SBFT as gold standard [25,33,34]. MDCT has a sensitivity and specificity of 95% and 96%, respectively, for advanced disease, but with only 70% sensitivity and specificity for early stage CD. Adding multiplanar image reconstruction to the axial data significantly increases the diagnostic confidence, even if it does not help identify additional lesions [9].

A classification of subtypes of CD was introduced as a guide for medical and surgical therapy: (1) active inflammatory, (2) fistulizing-perforating, (3) fibrostenosing, and (4) reparative or regenerative subtypes [35]. The characteristics of the active inflammatory subtype include focal inflammation; ulceration (superficial or deep); and activation of the lymphoid tissue with granuloma formation (Fig. 4). This subtype shows only subtle imaging changes in its mild form and can be difficult to determine with MDCT. Administration of IV contrast in combination with a neutral intraluminal contrast agent can increase its detection. Radiologists should be aware of the slight mucosal hyperenhancement and subtle wall thickening as signs of an early form of the active inflammatory subtype. The advanced inflammatory form is readily recognized on MDCT. The signs indicating activity are discussed later.

The active inflammatory type can transform into the fistulating-perforating type by progression of inflammatory activity through the bowel wall. This subtype clinically presents itself with recurrent sinus tracts, fistulae, and abscess formation (Fig. 5). MDCT gives information about fissuring ulcers, sinus tracts, and fistula, including course and organs involved [36].

The dominant feature of the fibrostenosing type is SBO. Narrowing and thickening of the involved bowel segment are seen on MDCT scans. The affected segment typically enhances after IV contrast administration but only moderately because of the fibrous nature of the tissue. In addition, there is no sign of active disease, such as bowel wall edema or mesenteric fat stranding. The stenosis can vary from mild to severe.

The regenerative or reparative subtype is histologically consistent with inactive CD. MDCT find-

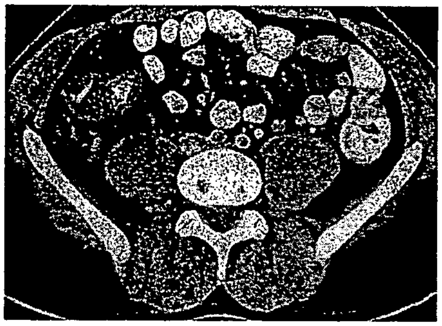

Fig. 4. Axial image of a 28-year-old woman presenting with fever, diarrhea, and right lower quadrant pain. This image is typical for an active inflammatory process in the ileocolic region. There is a marked thickening of the terminal ileum and cecum, stranding of the adjacent mesenteric fat, and enlarged lymph nodes. The wall of the terminal ileum shows multiple layers indicating active inflammation (*high attenuation*) and edema (*low attenuation*). Endoscopy proved active Crohn's disease.

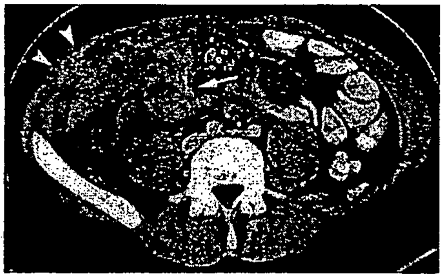

Fig. 5. Crohn's disease can lead to fistulae and abscesses such as seen in this 32-year-old man with known Crohn's disease. In this image there is a bowel-to-bowel fistula (*arrow*) and an abscess in the abdominal wall (*arrowheads*).

ings in this form of CD are submucosal fat replacement and bowel wall thickening with minimal IV contrast enhancement. Findings of active disease, such as mesenteric fat stranding and abscess formation, are not typically seen. Because the course of the illness is recurrent and presents with unpredictable relapses and phases of inactivity, these subtypes can change during the course of a patients' disease.

Besides detection of CD and subtype determination, MDCT can evaluate its activity [37]. Findings include thickening of the bowel wall with marked contrast enhancement; display of layering within the bowel wall [33,38]; local mesenteric hypervascularization (comb sign) (Fig. 6) [39,40]; mesenteric fat stranding; and detection of extraluminal findings, such as adenopathy, mesenteric abscess, and free intraperitoneal fluid [37].

These signs, either alone or in combination, have been correlated to clinical disease activity and symptoms. According to these studies the strongest signs for predicting high activity are mesenteric changes, such as fat stranding and abscess [37]. The comb sign, a sign of dilated and tortuous course of vessels in the inflamed segment, is also strongly correlated with activity [39,40]. The combination of lymph nodes and fibrofatty proliferation was studied in another trial and this proliferation was found to be significantly increased in patients with active disease [36]. Thickening of the bowel wall alone does not seem to be a sign of active disease, but the combination of thickening, hyperenhancement, and layering shows a significant correlation to disease activity (Fig. 7) [40].

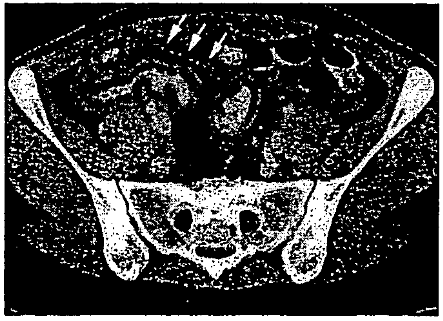

Fig. 6. Comb sign in Crohn's disease in 26-year-old woman. Adjacent to the thickened bowel loops there are small dots seen in the mesentery (*arrows*). These dots represent dilated vasa recta secondary to inflammation. This finding is known as the "comb sign."

For the detection of extraintestinal findings, MDCT is the method of choice [41]. Such methods as SBFT or endoscopy, which may be better in distinguishing mucosal changes, can only determine extraluminal disease in a very limited way. They may even fail to detect changes in the deep bowel wall that do not involve the mucosal surface. Compared with intraoperative correlation, MDCT is the most accurate imaging method in detecting abscess (91.8%), whereas for the detection of fistula, the sensitivity of MDCT is slightly lower (68%) than that of SBFT (73%), but both have the same specificity [25].

For imaging CD, MDCT is the modality of choice in the acute setting. It can provide the necessary information about the location, subtype, and activity of the disease and extraluminal findings, such as sinus, fistula, or abscess. For subtle mucosal changes,

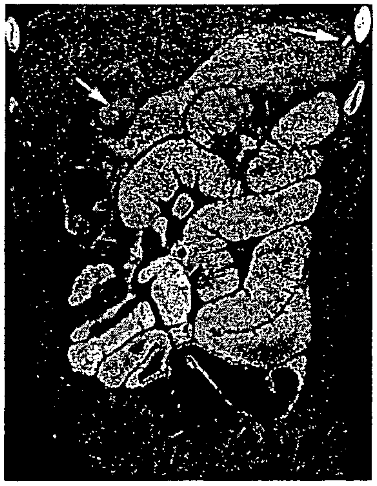

Fig. 7. This 43-year-old woman with known Crohn's disease underwent CT enteroclysis. The nasoduodenal tube is depicted in the stomach and duodenum (*arrows*). The entire small bowel has contrast and is well distended. The coronal reconstruction allows one to observe the thickening of the bowel wall in the distal small bowel. (Courtesy of Simon Wildermuth, MD, Zurich, Switzerland.)

SBFT is still better than MDCT and wireless capsule endoscopy may be the diagnostic method of choice for even earlier detection of disease.

### *Obstruction*

One of the leading causes for emergency admission in patients with acute abdomen is intestinal obstruction, accounting for about 20% of admissions for abdominal pain. Most intestinal obstructions are in the small bowel (~80%) and are related to postoperative adhesions (~60%), internal or external hernias (15%), or neoplasms (15%). Less common causes are inflammatory bowel disease, trauma, intussusception, gallstones, foreign bodies, and endometriosis, which account for about 10% of obstruction cases [42].

CT has a significant role in the diagnosis of SBO. The primary diagnostic tool remains the plain film (Fig. 8) [43]. For cost-effectiveness, plain film is the first imaging method of choice to diagnose SBO.

MDCT can provide additional information not possible with plain films and answer questions about the management of disease. Beyond "Is the bowel obstructed," however, the questions are (1) Where is the site? (2) What are the cause and severity of obstruction? (3) Is there a closed-loop obstruction or an obstruction complicated by ischemia (ie, strangulation)? [42], and so forth.

For the detection of SBO, the standard MDCT protocol includes IV contrast administration in the portal-venous phase. One variable to consider is oral contrast administration. In the standard diagnostic work-up, if an abdominal plain film has already diagnosed SBO, then the subsequent use of oral contrast for MDCT can be omitted because the contrast does not progress through an obstructed small bowel system.

The imaging features for the diagnosis of SBO by MDCT scans are thin-walled, dilated, and fluid-filled bowel loops [42]. The most important task after diagnosing SBO is to localize the point of obstruction or the so-called "transition zone" (Fig. 9) [44]. This zone is defined by dilated and air- or fluid-filled bowel loops proximal and collapsed loops distal to the site of obstruction. These findings are the most reliable to diagnose SBO by MDCT and to differentiate it from nonobstructive or paralytic ileus. The bigger the difference between dilated and collapsed bowel loops the easier it is to diagnose SBO by MDCT. The sensitivity and specificity of MDCT in depicting the transition zone varies in different studies [44,45]. In a series of patients with high-grade or complete SBO, the sensitivity and specificity were both reported as 96%. For diagnosing low or partial SBO, the sensitivity was only 63% [43]. The use of multiplanar reconstructions helps to determine the point of transition and to increase the diagnostic confidence.

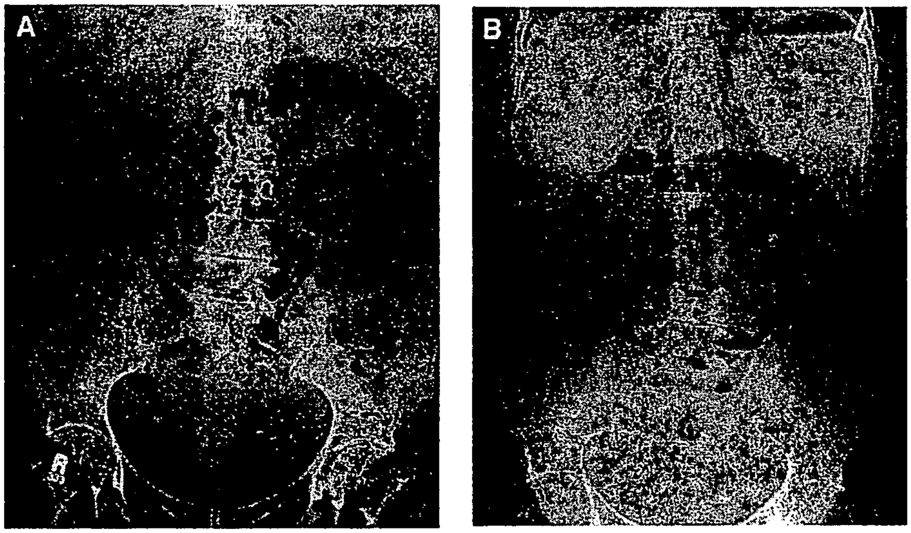

Fig. 8. Abdominal plain film findings of proximal bowel obstruction. Supine (*A*) and erect (*B*) plain film of the abdomen with dilated and air-filled segments. These findings indicate an obstruction with high positive predictive value. In patients with plain film findings suggesting obstruction, CT can help to localize the transition zone, the degree of distention, and the underlying reason for the obstruction.

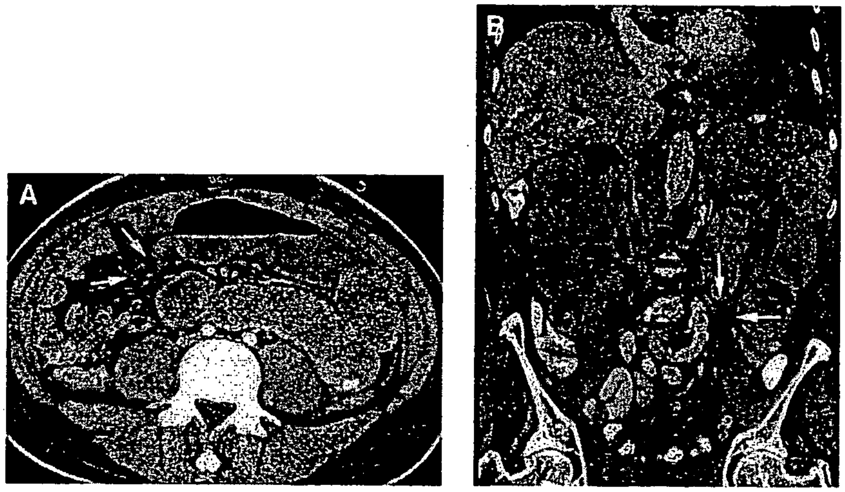

Fig. 9. Axial MDCT (*A*) and coronal reconstruction (*B*) show dilated proximal small bowel loops and collapsed distal bowel in the pelvis indicating a proximal obstruction. The distal small bowel segments, even collapsed, show dense oral contrast, suggesting an incomplete occlusion. The site of obstruction is the region where the bowel loops change from dilated to collapsed, called the transition zone (*arrows*).

MDCT is helpful in grading the severity of SBO and even in diagnosing its underlying cause (Fig. 10) [46,47]. The most common cause in SBO is adhesion. MDCT typically cannot display the actual adhesional band; however, a beaklike distortion of the transition zone without a defined lesion at the site of obstruction suggests this diagnosis. To differentiate complete versus partial SBO clinical evaluation and abdominal plain film findings provide most clues for diagnosis; MDCT can be of help in determining the degree of collapse in the distal segments and the amount of air or fluid and dilation in the proximal loops [48–50].

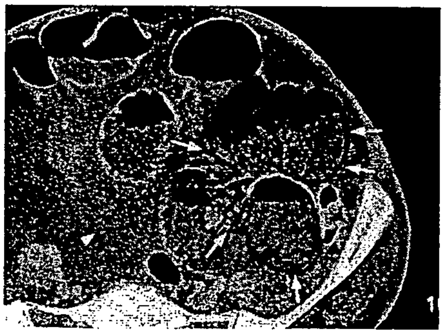

Fig. 10. There are markedly dilated bowel loops caused by obstruction. This obstruction led to underperfusion of bowel loops and to ischemia. The combination of obstruction and ischemia is known as "strangulation." The pneumatosis (*arrows*) and the ascites (*arrowhead*) indicate an advanced stage of ischemia with poor prognosis. (Courtesy of Walter Wiesner, MD, St. Gallen, Switzerland.)

It is important to diagnose closed-loop obstruction (incarceration) by CT and determine whether it is complicated by ischemia. Strangulation is suggested when there is bowel wall edema and mesenteric fat stranding caused by venous outflow obstruction (see Fig. 10) [51,52]. There is still debate about the capability of MDCT to detect vascular compromise in the case of closed-loop obstruction. A study found a 100% positive predictive value of MDCT for the detection of ischemic complications [53].

MDCT can effectively diagnose SBO and its underlying causes, particularly when multiplanar reconstruction is added to the axial images. Nevertheless, plain film radiology remains the method of choice to demonstrate SBO, with MDCT as the next step in diagnosing the obstruction, locating the transition zone, grading the severity of disease, and finding the underlying disease.

### *Ischemia*

Especially for older patients, small bowel ischemia is a rare but often underestimated reason for acute abdomen in daily practice. According to a recently published prospective study, about 8.2% of a nonselected study population presenting with acute abdomen had acute bowel ischemia, 48% of which were small bowel ischemia [54]. The key issue with mesenteric ischemia is its high mortality of more than 50% if not diagnosed and treated in a timely fashion [55–58].

The etiology of acute intestinal ischemia is diverse with most cases caused by either arterial or venous occlusion [59]. In a minority of cases bowel ischemia has a nonocclusive nature caused by low flow rates and hypo-oxygenation of the tissue, such as in cases of hypovolemic shock.

Acute occlusion of the superior mesenteric artery occurs in about 60% to 70% of cases because of thrombosis or embolization. Mesenteric venous thromboses are responsible only for 5% to 10% and nonocclusive conditions for 20% to 30% of cases [60].

Angiography is still the imaging method with highest detection rates for an acute vascular occlusion diagnosis and most of cases of bowel ischemia [61]. Angiography is highly invasive, however, and cannot display other reasons for acute abdomen, which is problematic especially in older and unstable patients. Because acute intestinal ischemia is a rare disease, invasive procedures are performed late in the diagnostic process, leading to a potentially fatal delay in diagnosis and therapy. MDCT has the advantage of depicting a large range of diagnoses in the setting of acute abdomen by covering not only the vascular system (Fig. 11). It also has a similar accuracy than angiography to detect ischemia but because of its noninvasiveness it is performed much earlier in the diagnostic process. Angiography has a sensitivity of 87% in diagnosing bowel ischemia [61], whereas the sensitivity with MDCT for acute ischemia was of 80%, the specificity was 98.51%, positive predictive value was 90.48%, and negative predictive value was 98.15% [54].

Ideally, the MDCT protocol for acute abdomen should be changed to include an arterial phase in combination with the use of neutral peroral contrast. Such an altered protocol for bowel ischemia could increase the ability to detect it in the first diagnostic test and facilitate the work-up for these patients. Because it is a rare disease, an arterial phase is normally not included in the routine emergency setting in the acute abdomen MDCT protocol.

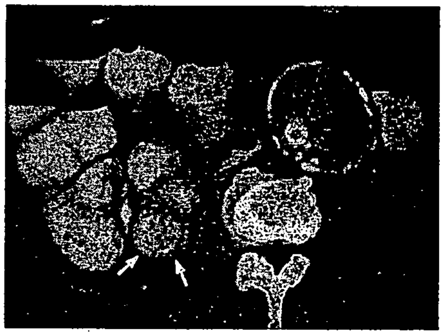

Fig. 11. This 78-year-old man presented with acute abdominal pain 4 days after aortic aneurysm repair. The MDCT scan without intravenous contrast shows slightly thickened small bowel loops in the right lower quadrant (*arrows*). These findings indicate early ischemic changes in the small bowel caused by the postoperative occlusion of the superior mesenteric artery. (Courtesy of Walter Wiesner, MD, St. Gallen, Switzerland.)

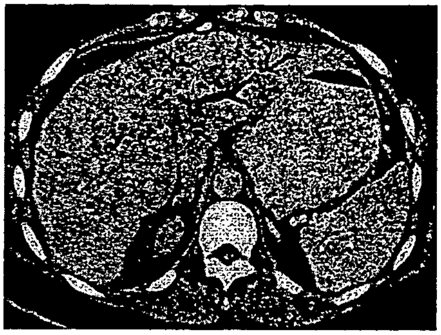

Fig. 12. Contrast-enhanced axial CT slices of the liver in a patient with acute transmural mesenteric ischemia shows intrahepatic portal venous gas.

Image findings for patients with acute ischemia are wall thickening, mesenteric stranding, and mesenteric fluid. Pneumatosis of the bowel wall and portal venous gas are seen in more severe cases (Fig. 12) [54,62,63]. Given the appropriate protocol, the occlusion itself can be seen and can either be atherosclerotic, thrombotic, or iatrogenic following vascular intervention or operation. Multiplanar reconstructions in the coronal and saggital plane can help tremendously to diagnose occlusion of the mesenteric vascular system. MDCT can detect bowel ischemia with a sensitivity of 80% and a specificity of 98%. One should be aware of the disease in the emergency setting and include it in the differential diagnosis of the acute abdomen.

### *Neoplasms*

Small bowel neoplasms are uncommon, representing fewer than 25% of all gastrointestinal neoplasms and fewer than 2% of all malignant tumors. The annual incidence of small bowel tumors is only 0.5 to 1 per 100,000 population in the Western world, accounting for 5260 new cases and 1130 deaths in the United States in 2004. There is a slight male predominance, and patients are mostly in their fifth decade [64].

Early diagnosis of small bowel tumors poses a significant challenge to clinicians and radiologists. Patients often present with nonspecific symptoms, such as abdominal pain or intestinal bleeding. Fur-

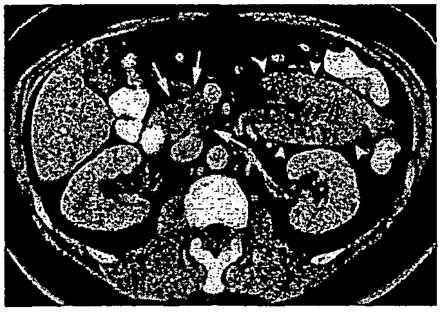

Fig. 13. Contrast-enhanced axial images of a patient with adenocarcinoma of the small bowel. The mass is located in the bowel wall and extends in the surrounding fat in an exophytic manner (*arrows*). Longer segments of the small bowel are affected in this patient showing a loop with diffuse wall thickening (*arrowheads*).

thermore, small bowel tumors tend to be small in early stage and difficult to diagnose.

In patients with suspected neoplasm, the administration of IV contrast has to be modified for imaging in all phases. The use of neutral oral contrast should be considered. Distention is crucial for the detection of small lesions in the bowel wall. Although no hard evidence exists, CT enteroclysis could well be the method of choice at this time because of its capacity for absolute control of distention [20]. If new noninvasive distention methods, such as mannitol, Locust beam gum, or the commercially available VoLumen, prove to produce sufficient distention, these would be the choice methods because of its noninvasiveness and patients' comfort and safety.

Adenocarcinoma is the most common primary tumor of the small intestine accounting for 40% of small bowel neoplasms [65,66]. Most of these tumors are located in the duodenum. MDCT findings for adenocarcinoma are typically a focal area of wall thickening encasing the lumen (Fig. 13). Because these tumors have a fibrotic and rigid consistency, an early sign can be obstruction. CT can localize the tumor and stage it by determining local extension, adenopathy, and metastasis [67]. The liver is the organ most commonly affected by distant metastasis in small bowel adenocarcinoma. Typically, metastases of small bowel adenocarcinoma appear as low-attenuation masses in the liver, which are visualized best during the portal venous phase of enhancement [68].

The second most common primary small bowel neoplasm is carcinoid, representing approximately 25% of all primary small bowel tumors [64]. These tumors are more common in the ileum than in the jejunum and duodenum. About 30% of carcinoid tumors are multicentric, which makes its correct diagnosis and staging difficult with MDCT [69]. In advanced stages, carcinoid tumors grow into the mesentery, with a fairly characteristic appearance on MDCT (Fig. 14) [70]. Calcifications are seen in up to 70% of cases [71,72]. Carcinoid tumors typically metastasize to the liver and normally present as multiple small liver lesions enhancing strongly in the arterial phase.

The third most common malignancy is non-Hodgkin's lymphoma, representing approximately 10% to 15% of all small bowel neoplasms [64].

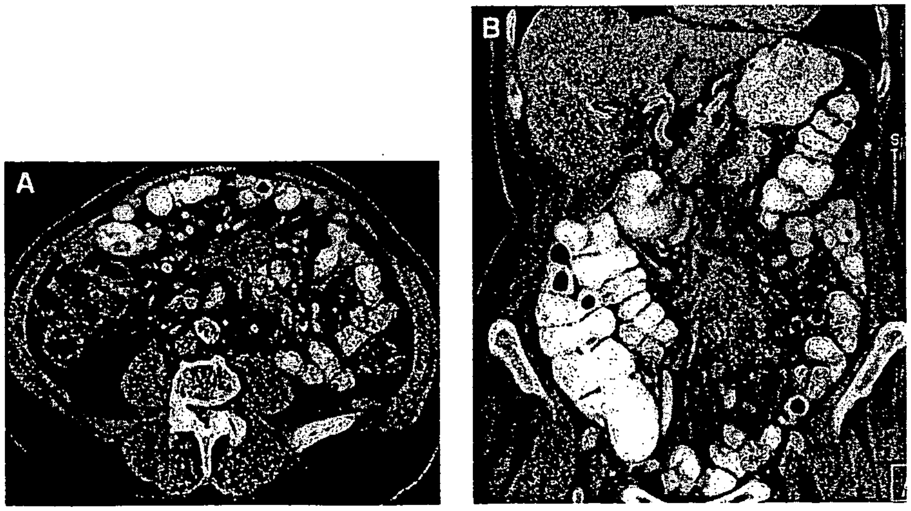

Fig. 14. Contrast-enhanced axial image (*A*) and coronal reconstruction (*B*) of a patient with carcinoid demonstrate a tumor arising in the bowel wall and spreading through the mesentery producing a large mass with central necrosis.

The most common location is in the stomach, but it can occur in any part of the gastrointestinal tract [73]. Several patterns can be seen by imaging [69]. Non-Hodgkin's lymphoma can appear as either multiple small nodules, best seen on small bowel series, or as a single mass of variable size (Fig. 15). This mass can lead to intussusception but rarely causes obstruction because lesions are typically soft and smooth. Infiltrating lymphoma produces a different type of pattern with diffuse wall thickening and destruction of the normal small bowel folds without obstruction. This type of lymphoma commonly infiltrates the muscular layer and disrupts the myoenteric plexus, causing aneurismal dilation of the affected segment in up to 50% of cases [74]. The fourth pattern of lymphoma is an exophytic mass, which can ulcerate. This appearance is very similar to adenocarcinoma or gastrointestinal stromal tumor.

Lymphoma can also be manifested in mesenteric adenopathy and, as the tumor grows, can encase small bowel loops and mesenteric vessels. After IV contrast administration the vascular encasement (bright) of the normal vessels going through the enlarged lymph nodes (lower density on top and at base) is called the "sandwich sign" [2].

The fourth most common primary small bowel tumor is gastrointestinal stromal cell tumor [64], which arises from smooth muscle cells within the bowel wall. It commonly involves the jejunum and the ileum. Gastrointestinal stromal cell tumors are rare, representing only 9% of small bowel tumors; they are slightly more common in males and typically occur in the fifth to the sixth decade of life [75]. Typically, gastrointestinal stromal cell tumors appear as large, bulky, masses (Fig. 16). Central necrosis and ulcerations are common. Tumor spread is through local extension into adjacent organs and hematogenously to the liver. Liver metastasis can appear either as hypovascular or cystic masses. Peritoneal metastasis may also be seen [76–79].

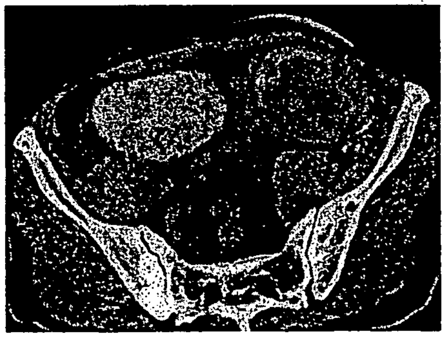

Fig. 15. Axial CT image of a 68-year-old man with abdominal pain. On the CT there is a large mass in the small bowel wall obliterating the lumen and producing an obstruction. Surgery revealed a large small bowel lymphoma.

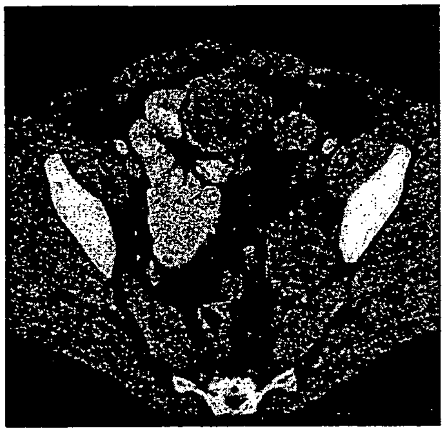

Fig. 16. Contrast-enhanced axial CT image of a patient with metastatic gastrointestinal stromal tumor. The metastatic masses are round-shaped and arise from distal ileal loops.

In a 10-year review of small bowel cancers in a large United States teaching hospital, 50% were primary tumors and 50% were metastatic masses; 43% of the metastases were from colonic cancer, 11% were each of pancreatic and ovarian cancer origin, 9% were from lung cancer, and 6% were melanoma (Fig. 17). The remaining was metastasis from gastric lymphoma and adenocarcinoma, breast, bladder, ureteral, and testicular cancer [66].

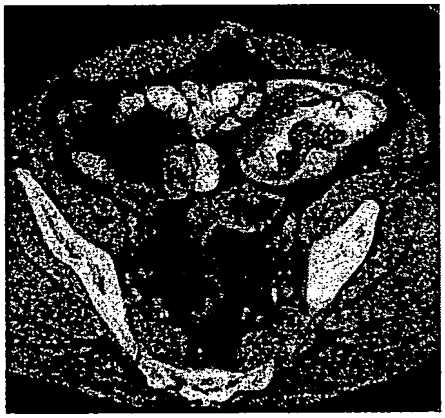

Fig. 17. Contrast-enhanced axial CT image of a patient with known melanoma and lower abdominal pain. The CT shows a thickened bowel wall of the distal ileum. The findings are consistent with melanoma metastasis, which was surgically proved.

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